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PRINCETON, N. J.

SAVING COAL IN STEAM POWER PLANTS

Reprint of Engineering Bulletin No. 2

PREPARED BY THE UNITED STATES FUEL ADMINISTRATION

IN COLLABORATION WITH THE
BUREAU OF MINES

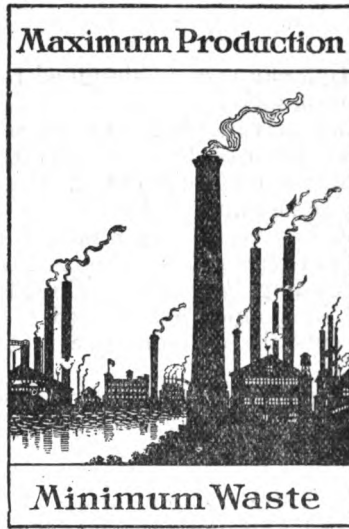


WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

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Economy in any power-plant proposition absolutely demands definite knowledge (1) as to whether coal would be saved by purchasing power on the one hand or generating the power in a privately owned plant on the other hand, and (2) if the decision is in favor of the latter alternative how to save coal and obtain maximum production with minimum waste.

The object of this bulletin is to set forth the underlying principles, the determining factors, and the method of applying them to the problems in hand in such manner as to be of greatest service to the owner, manager, and engineer.

SAVING COAL IN STEAM POWER PLANTS.

ISOLATED PLANT VERSUS CENTRAL STATION POWER.

A. If the available power purchased or privately generated is obtained purely from a hydroelectric service its use will, of course, save fuel over any steam-power proposition. If, however, in a steam plant all the exhaust steam were sufficiently utilized the boilers would still have to be operated at about 90 per cent¹ of their former output to supply the heating steam (even if at low pressure) if the engines were shut down, and the saving in coal would be only 10 per cent instead of 100 per cent.

B. If the purchased power is produced in a central steam plant capable of delivering a kilowatt hour for, say, $2\frac{1}{2}$ pounds of coal, then its use will waste or save in comparison with a private steam plant, as follows:

B-1. If all the exhaust steam from any design of private plant is absorbed by heating and process work, no central power station²

¹ Exhaust steam contains, within a few per cent, as much heat as direct steam. Thus an engine or turbine with steam consumptions of 20 pounds and 60 pounds per indicated horsepower hour will discharge in the exhaust about 88 to 96 per cent of the heat of the steam admitted at the throttles respectively. In the examples given 90 per cent is assumed.

² Operating condensing in accordance with standard practice. If a central plant were designed to furnish exhaust steam to its customers it could then compete on a coal basis with the private plant. This is the sound theory of the "city block" or "district" system of power and heating.

of condensing operation can ever be designed to compete with it in the matter of coal consumption.

If the engines in this private plant were all removed it would still require 90 per cent as much coal as formerly to make low-pressure steam for heating, and outside current at $2\frac{1}{2}$ pounds per kilowatt hour would still have to be purchased.

If the private plant had been using 8 pounds of coal per kilowatt hour it would save eight-tenths of a pounds of coal to replace which it would buy current costing $2\frac{1}{2}$ pounds. Thus, for each pound saved in the private plant $3\frac{1}{3}$ pounds are burned in the central station. This example represents the extreme case in favor of the private plant.

B-2. If the same private plant operating noncondensing wastes all of its exhaust steam, coal will be wasted in the ratio of 8 to $2\frac{1}{2}$ per kilowatt used. Coal will be saved by substituting purchased power. This example represents the extreme case in favor of the central station current, and the ratio is 8 to $2\frac{1}{2}$ or 3.2 to 1.

To sum up cases B-1 and B-2, the use of exhaust steam is the determining factor. Where it is all used the small private plant generates its energy as a by-product of its heating. The engine or turbine acts as a pressure reducing valve between the boiler and the heating system, and abstracts a small percentage (3 to 12 per cent) of heat from the steam. Therefore shutting down the engine will save only this small fraction of the total coal. For most cases of this kind it is safe to say the engine absorbs less than 10 per cent of the heat or fuel. As a matter of fact, many cases could be quoted where no saving of coal occurs when the engines are shut down.¹

Hence for purposes of approximate calculation the power is a pure by-product of the heating. But assuming 10 per cent of the heat of the steam to be taken by the engine, then only 10 per cent of the coal consumption will be saved if the heating is done by direct steam. Eight pounds of coal per kilowatt hour, the figure assumed, is based upon an extravagantly wasteful boiler plant, but even under these conditions the small private plant using all its exhaust would save coal over central station current for power in a ratio of $3\frac{1}{3}$ to 1.

If on the other hand no exhaust steam is used in the same private plant, the saving in favor of the central station power is in the ratio of the coal used per kilowatt hour for the two cases, or with the figures assumed, 8 to $2\frac{1}{2}$, that is 3.2 to 1.

It is evident that in a noncondensing private plant, as the use for exhaust steam decreases a certain point will be reached where the same coal consumption would obtain by the generation of power by either type of plant. A still further reduction in the utilization of exhaust would then throw the balance in favor of central station power.

This critical point of equal total coal consumption depends upon the coal consumed per kilowatt hour in the private plant and the central plant, respectively. Thus if the central station has a coal rate of 3 pounds per kilowatt hour and the private plant 6 pounds, the critical point is reached when $1 \text{ minus } 3/6 = 1/2$ of the exhaust or

¹ There are sound technical explanations for these cases, but it is aside from present purposes to enter a detailed discussion.

coal is needed for¹ heating, and the same total coal will be consumed whether the power is purchased or the engine operated. If less than one-half of the exhaust is used, the purchased current will effect a saving; if more than one-half of the exhaust is used, running the engine in the private plant will save coal.

Take another case and assume that current can be supplied at the purchaser's switchboard for 2 pounds of coal, and that the small plant produces it for 5 pounds. Then, if $1 \text{ minus } \frac{2}{5} = \frac{3}{5}$ of the coal or exhaust is needed for heating no change in total coal consumption will occur if current is purchased, the engines shut down and boilers operated for heating only.²

If the coal per kilowatt hour for outside current is less than the same figure for the private plant, the most coal will be conserved by carrying just enough load to furnish exhaust for the heating and buying the surplus power. Thus the small plant obtains a part of its power as a by-product of its heating and buys the balance for the least total coal consumption. This method saves more coal than shutting down the small plant entirely, even when a saving would be thus effected. There are many cases where at night or during nonheating months where an important coal saving can be made by buying the power which is in excess of that required to furnish exhaust for heating.

Still another situation is met when the private plant is of modern design and operates solely for generation of power. Such cases would be determined purely on a comparison of the coal consumed per kilowatt hour. Central station power is produced at consumers' switchboard from a minimum of about $1\frac{3}{4}$ pounds of coal in the largest and most modern plants up to 3 pounds, 4 pounds, 5 pounds, and upward in less efficient stations.

In moderately large private plants of good design a kilowatt hour is produced for a little over 2 pounds, while less efficient and smaller plants consume up to 10 pounds and over. In this whole problem it is necessary to regard *coal* as the basis of economy and *not money* as heretofore. Central station interests and private consumers should patriotically endeavor to meet each other half way in sacrificing by reduced rates or increased expense when important economies *in coal* are at stake.

¹ The proportion of exhaust required for heating represents almost the same proportion of coal which will have to be burned for direct steam heating if the engine is replaced by purchased power.

² Equal coal consumption obtains when the proportion of total coal required for heating alone equals one minus the fraction obtained by the ratio of the kilowatt hour coal consumptions of the isolated plant to the central plant figured from the purchaser's switchboard. Example: With purchased current at 4 pounds of coal and private power at 7 pounds, an equal coal consumption with either system will obtain when the proportion of coal required for heating is $1 \text{ minus } \frac{4}{7} = \frac{3}{7}$ of the total coal.

PART II.

After due consideration has been given to the questions brought out in the previous discussion and if it has been determined that the plant is justified in continuing to operate, attention must be given to those points having a bearing on economical operation. No transformation of energy can take place without appreciable loss, and every effort should be made to keep the various losses down to a minimum. Diagram A shows a typical distribution of heat in a medium-sized hand-fired plant.

STOPPING FUEL WASTE.

Beginning at the grates upon which the fuel bed rests, see that the air spaces are properly proportioned to avoid loss of combustible material into the ash pit. This will depend on the kind of coal used. Study the fuel with this point in mind. Five per cent is not an unusual loss from this cause.

The amount of grate surface is important, as it determines the rate of combustion. Ratios of grate area to boiler heating surface will vary from 1:35 to 1:60, depending on the characteristics of the coal and whether hand fired or stoker fired. For power purposes in hand-fired plants do not permit the rate of combustion to fall below 15 pounds of coal per square foot of grate surface per hour, or go above 28 pounds with bituminous coal. With stokers the rate may be as high as the design of plant and the draft will permit. With the fine-steam sizes of anthracite the rate of combustion should not be less than 10 pounds.

With settings tight to prevent infiltration of air, heating surface clean, radiation losses reduced by proper covering, piping and steam mains lagged, engine valves tight and properly set, all condensation returned to the feed-water heater a good start will have been made in fuel conservation.

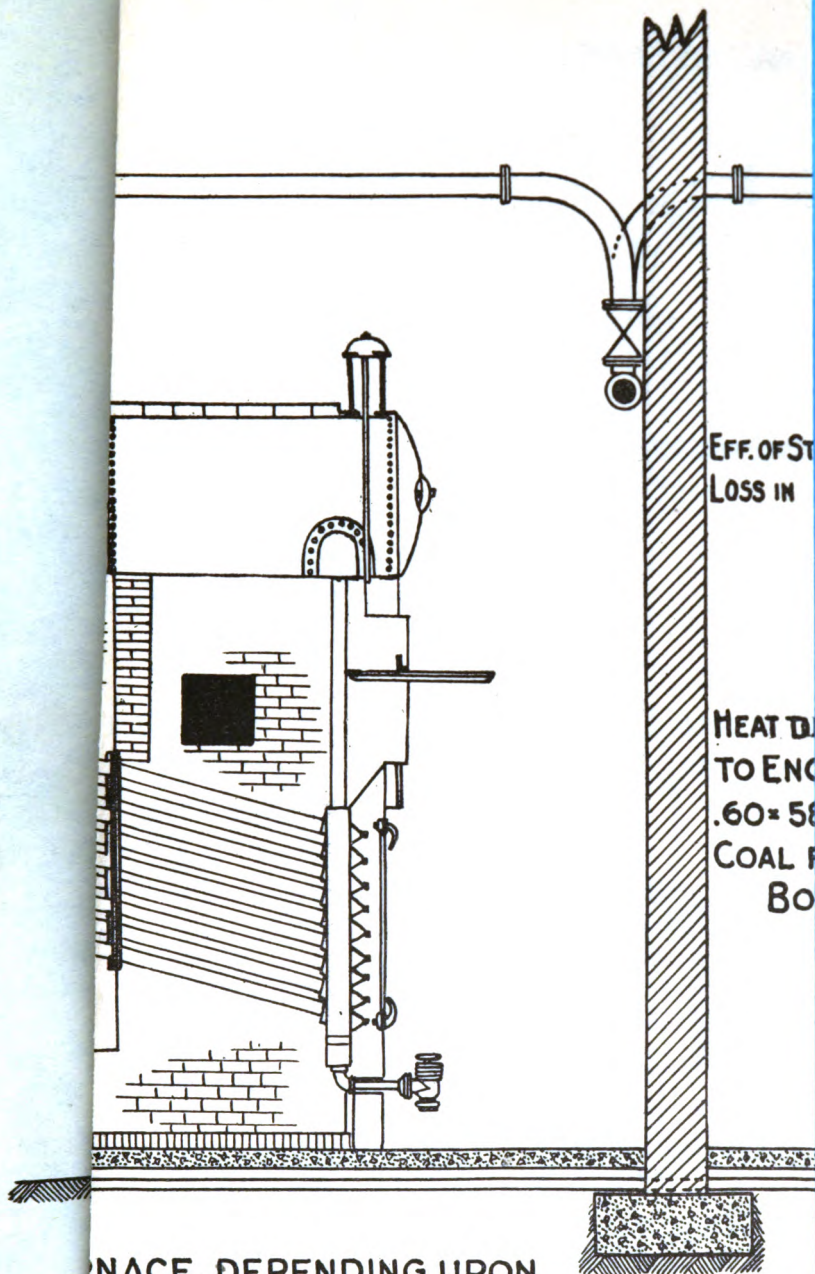
HUMAN ELEMENT IMPORTANT.

However, merely placing the plant in good physical condition will not suffice. Conditions change from day to day, from hour to hour, even from moment to moment. These changes must be interpreted, and the degree of intelligence with which they are interpreted marks the degree of success which will be realized in fuel saving.

A good plant poorly operated will show low efficiency, while a poor plant skillfully operated will sometimes show a relatively high efficiency. Therefore,

$$\begin{aligned}\text{Ultimate efficiency} &= E \times H \\ \text{Where } E &= \text{Equipment} \\ \text{and } H &= \text{Human element.}\end{aligned}$$

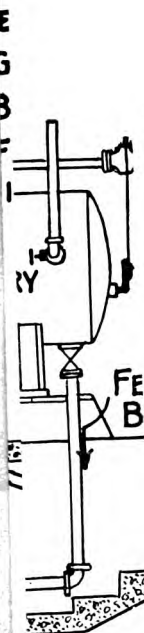
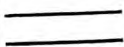
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NACE, DEPENDING UPON
PERATION, MAY RANGE

CONS

ABLE
PROCESS



FHEATIN

CHECK OPERATION CLOSELY.

Find out what the boilers are doing. Provide facilities for weighing the coal; for measuring the feed water; for checking up on combustion; for determining draft; for taking temperature readings at important points. To appreciate the significance of the above items it is desirable to become familiar with the literature of power-plant operation. Read Bulletin No. 1 of the United States Fuel Administration on Boiler and Furnace Testing, Technical Paper No. 80, and various other publications of the Bureau of Mines. In small and moderate sized plants, hand fired, a boiler efficiency of 60 to 70 can be expected, while in medium-sized stoker-fired plants 70 to 75 per cent should be realized. In any given plant determine what efficiency should be expected, considering load and equipment, and keep the plant up to mark set.

PRINCIPAL LOSSES.

The chief losses in boiler-plant operation are:

Cause.	Remedy.
1. Dirty boiler—loss up to 25 per cent-----	Clean boiler.
2. Leaky setting—loss up to 15 per cent-----	Tight setting.
3. Poor firing—loss up to 40 per cent-----	Good firing.

1. A boiler may be dirty on the inside or outside or both. Dirt on the inside is due to scale formation and can be corrected by cleaning the boiler and then giving consideration to the character of the feed water and its proper treatment. See Engineering Bulletin No. 3 of United States Fuel Administration.

Outside cleaning must receive careful attention. A slight accumulation of soot deposited in a few hours' run will result in a growing loss of efficiency. Some one must be delegated to follow up this matter of soot and see that the cleaning is done thoroughly, frequently, and regularly.

2. Air leaks reduce efficiency. The ordinary brickwork setting develops cracks and crevices which allow a considerable amount of air to enter the setting, lowering the temperature of the gases of combustion. The porous character of the brick itself is such that an appreciable leakage takes place through the walls.

The remedy is to point up the brickwork with plastic fireproof mixture and paint or cover the setting with a coat of air-tight material.

3. Bad firing includes allowing holes to develop in fuel bed; carrying an uneven fire; carrying too thin a fire; carrying too thick a fire; stirring fire, thus forming clinkers; and improper manipulation of dampers. It is here that the human equation becomes of most importance. Attention concentrated on what takes place from day to day in front of the boilers will pay greater returns for the time spent than in any other part of the plant.

POWER PLANT RECORDS.

The importance of keeping a systematic record of operation can not be overestimated. In this way affairs in the power plant are lifted from the realm of guesswork to certainty. While the system adopted for the ordinary plant may be very simple, the records should be arranged for convenient reference so that comparisons of

results with past performance may be made. Thus it is possible to note the effect of changes in equipment or methods and improvements in economy or the reverse may be at once detected.

ENGINE ROOM.

After the steam has been delivered to the engine, care should be taken to see that it is utilized to best advantage. Where all the steam is needed, the economy or rate of the engine itself is not of particular consequence; that is, a simple slide-valve engine using steam at the rate of 40 or 50 pounds per horsepower may be the most desirable type to use. This all depends on circumstances. As the demand for exhaust steam decreases, the importance of economy in the engine increases. Should there be periods during which all of the exhaust is not used, the maximum economy of the engine during these periods is of utmost importance. At such times the most economical generating unit should be selected and one of a size that will be economically loaded with the amount of power developed.

USE OF EXHAUST PRINCIPAL FACTOR.

A portion of the exhaust should be used for heating the feed water to the highest temperature practicable; not less than 200° in any event.

Exhaust mains should be pitched in the direction of flow, drained and trapped, and the condensation returned to the heater. Use no live steam where the work can be done with exhaust. To get the most efficient transfer of heat the radiating surface of coils and other heating elements should be properly disposed to promote circulation of the heat-absorbing medium, whether air, water, or other liquids. Large increase in efficiency or capacity can sometimes be made in old systems by a little attention to this feature.

In the case of stills, evaporators, or triple effects in which deposits of suspended or residue matter is liable to form, periodical cleaning of the coils is essential.

Venting radiators and steam lines of air should receive careful attention. See Engineering Bulletin, No. 6, on Saving Fuel in Heating Systems. For large systems vacuum returns are recommended. Direct radiation should be checked up with special respect to location in order that heat loss through exposed walls and windows shall be taken care of efficiently.

A study of the accompanying heat balance diagram will serve to indicate the small portion of the heat developed by the fuel which is used in generating power.

Do not therefore assume that the steam after passing through the engine is a waste product. It still represents a large percentage of the heat delivered by the boiler. Save it wherever possible. It is the principal product of the plant. The power is the by-product.

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